Journal of Forensic and Legal Medicine 20 (2013) 947–952

Contents lists available at ScienceDirect

Journal of Forensic and Legal Medicine

journal homepage: www.elsevier.com/locate/jflm

Original communication

Estimation of stature by using lower limb dimensions in the Malaysian population

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ARTICLE INFO

Article history:
Received 13 February 2013
Received in revised form
23 August 2013
Accepted 7 September 2013
Available online 18 September 2013

Keywords:
Stature
Forensic anthropology population data
Malaysian
Thigh
Lower leg length
Foot height

ABSTRACT

Estimation of stature is an important step in developing a biological profile for human identification. It may provide a valuable indicator for an unknown individual in a population. The aim of this study was to analyse the relationship between stature and lower limb dimensions in the Malaysian population. The sample comprised 100 corpses, which included 69 males and 31 females between the age range of 20–90 years old. The parameters measured were stature, thigh length, lower leg length, leg length, foot length, foot height and foot breadth. Results showed that the mean values in males were significantly higher than those in females ($p < 0.05$). There were significant correlations between lower limb dimensions and stature. Cross-validation of the equation on 100 individuals showed close approximation between known stature and estimated stature. It was concluded that lower limb dimensions were useful for estimation of stature, which should be validated in future studies.

1. Introduction

Anthropometry may be defined as a technique of expressing the quantitative form of human body. It is recognised as the single most universally applicable, inexpensive and non-invasive technique for assessing the size and proportions of the human body.[1] This technique has been used by anthropologists worldwide to estimate body size and stature for many years.[2,3] Besides race, age and sex, stature is one of the vital features of identification. Thus, developing a biological profile in stature is an important step for human identification.[4]

Stature is usually estimated by employing either the anatomical or mathematical method. The anatomical method is based on a summed height of skeleton or human pieces contributing to stature in human. Nevertheless, the main disadvantage in this method is that nearly complete pieces of bones are needed for stature.[5,6] On the other hand, the mathematical method makes use of either one or more bone lengths to estimate stature. This method employs bone length, stature tables and regression formulae to estimate total skeletal height from long bones.[5,6] Most studies have used the mathematical method, which utilised long bones of upper and lower extremities.[1–9] Additionally, skull and post cranial elements have also been used for stature estimation.[5]

Of all stature predictors, long bones of lower extremities have been extensively used in stature estimation.[7] Studies have shown that femur is more reliable in estimating stature compared with the aforementioned skeletal elements such as metatarsal, metacarpal, calcaneum and fragmentary tibia.[2] Further, femur is less influenced by nutritional and other environmental stresses than the more distal bones of the limbs.[4] The femur in intact state showed the highest correlation with stature, and yields the best

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http://dx.doi.org/10.1016/j.jflm.2013.09.006

Table 1
Landmarks and techniques used in taking anthropometric measurements.

No.	Landmarks	Definition	Instrument	Technique
1.	Height-vertex (stature)	Stature of the body was measured from the vertex with the head in 'Frankfort horizontal plane' to the heel with the body in supine position. **Vertex**: It is the highest point on the head when the head is in supine position ('Frankfort plane').	Long ruler	The body was lying supine, and measurement was taken when the body was fully unclothed. The ruler was held on the table, and measurement was taken from the vertex to heel in that position.
2.	Thigh length (*TL*)	It is the distance from the midpoint of inguinal line to inferior border of patellar. Surface thigh length has been shown to provide the highest correlation with stature.[5]	Measuring tape.	The body was lying supine, and measurement was taken by using a measuring tape. The midpoint of groin was held with the measuring tape by the right hand, and movement of the tape was controlled to extend to the inferior border of patella, in oblique plane with regard to length. No pressure was made on the body surface to reduce possible error in contact measurements.
3.	Lower leg length (*LLL*)	It was measured from the lateral knee joint to the heel.	Measuring tape.	The measurement was taken from the lateral knee joint by the right hand, and movement of the tape was controlled to extend to the heel.
4.	Leg length (*LL*)	It is the distance from the lateral knee joint to lower border of lateral malleolus.	Measuring tape.	The measurement was taken from the lateral knee joint by the right hand, and movement of the tape was controlled to extend to the lateral malleolus.
5.	Foot height (*FH*)	It is the difference between *LLL* and *LL*.		
6.	Foot breadth (*FB*)	It is the distance between the distal first metatarsal, the prominence of the medial side of foot, and distal fifth metatarsal, the prominence of lateral side of foot.	Sliding calipers.	The left foot was held with the heel resting backward, and measurement was taken across the dorsum of foot between the two prominences of side of foot, as in preceding measurement, in oblique plane with regard to length.
7.	Foot length (*FL*)	It is the distance from the most prominent part of the heel to the distal part of the longest toe (second or first).	Measuring tape.	The measurement was taken across the dorsum of foot between the two prominences of foot as in preceding measurements, in vertical plane with regard to length.

accuracy,[2] probably because it contributed most to the living height.[4] For instance, estimation of stature in the Americans, who died in the first half of the 20th century was based on measurements of femur.[4]

Stature estimation may be specifically derived from each population. Specific regression for specific population is important to account for inherent population variations[9–11] such as genetic and environmental factors.[3] Also, the regressions will take into account

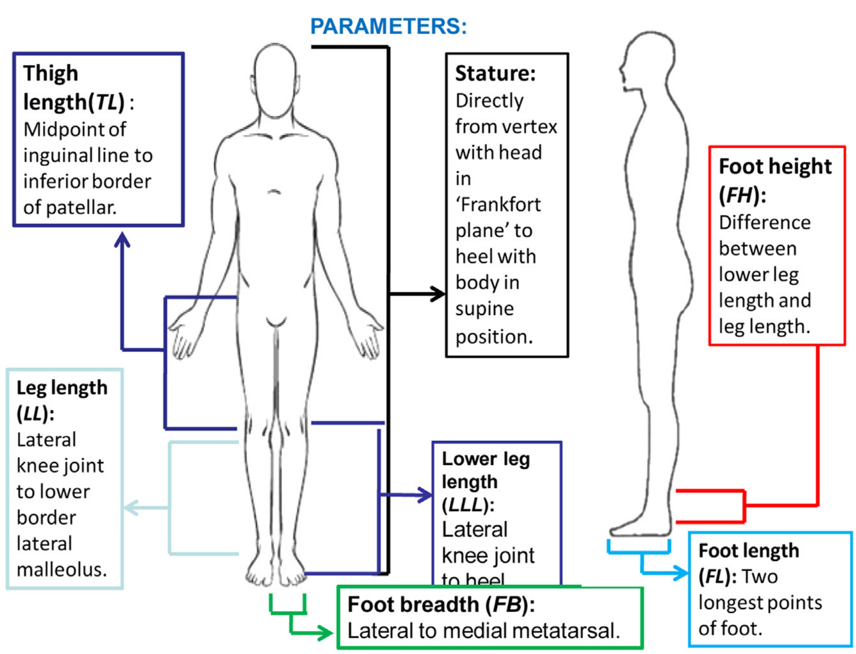

Fig. 1. Illustration to show the reference points on the body.

human internal factors such as sex and age-related changes.[2,8] The regression equations used among the indigenous South African population group were derived from fragments of femur.[2] The Bulgarian and Thai populations have also used lower limbs in stature estimation.[4,8] Thus far, stature estimation had been done mostly by using the regressions based on the European and American population, and these regressions may not be applicable to the Asian population.[7] The fact that there was paucity of study for stature estimation in the Malaysian population, it is certainly warranted to produce regressions based on the population. Hence, the aim of this study was to perform measurements of lower limb parameters for stature estimation in the Malaysian population. The specific objectives were to determine correlations between stature and lower limb parameters, and to produce regressions for stature estimation.

2. Materials and methods

The human bodies were obtained from two hospitals in Kuala Lumpur, which included the Universiti Kebangsaan Malaysia Medical Centre and the National Institute of Forensic, Hospital Kuala Lumpur. In this study, 100 deceased persons were sampled, which comprised 69 males and 31 females between 20 and 100 years of age. Literature showed nearly 51.2% of the total population in Malaysia were males, and 48.8% were females.[12] The sample represented an admixture of major races namely, Malay, Chinese, Indian and the minorities. Bodies with bone pathology, trauma, surgical procedures, decomposed bodies, skeletal abnormality and deformity were excluded from this study. No bodies were excluded from the study at the time of study. The human bodies were fresh and not embalmed. An ethical approval (FF-218-2012) for the study was obtained from the institution.

Six lower limb parameters namely, thigh length (*TL*), lower leg length (*LLL*), leg length (*LL*), foot height (*FH*), foot breadth (*FB*) and foot length (*FL*) were measured (Table 1; Fig. 1). According to the procedure described by the 'International Biological Program',[13] measurements from the left side of the body tend to be more reliable than the right side.[14] Hence, the measurements in this study were taken from the left lower limbs. Measurements were performed by two observers, and average values were taken. The measurements were taken in centimetres (*cm*), and were measured to two decimal places. The measuring instruments used were a long ruler (Marsden Height Measure, *UK*) with precision of 10 mm, a measuring tape (Goldfish, China) with precision of 10 mm and a sliding calipers (Absolute Digimatic, Japan) with precision of 0.01 mm.

In this study, a statistical package (*SPSS* for windows, Version 20.0) was used to analyse the results.[15] The sample size for human samples were sufficient by using the statistical power calculations.[16] The dependent parameters in the samples were represented by six lower limb parameters. Correlations between lower limb parameters and stature were determined by using the Pearson's correlation test. The regressions were produced based on various combinations of the parameters by stepwise regression analysis. Comparison between measured and estimated statures was analysed by using paired *T*-test. The intra- and inter-observational analysis were analysed by using paired *T*-test and independent sample *T*-test, respectively.

Table 2
Descriptive statistics for lower limb dimensions, age and stature in males and females.

Parameters	Males ($n = 69$)				Females ($n = 31$)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Age	59.10	14.93	20	88	64.23	14.97	28	90
St	164.84	7.21	149.1	186.1	152.62	6.38	140.0	165.3
TL	44.42	3.29	36.2	54.0	40.59	2.71	35.4	45.0
LLL	47.21	2.87	41.4	56.4	43.46	2.65	38.8	49.3
LL	41.51	2.71	36.2	49.7	38.20	2.42	33.4	42.4
FL	24.01	1.66	20.6	28.0	21.98	1.34	20.1	26.5
FB	9.24	0.57	7.7	10.5	8.44	0.60	7.4	9.4
FH	5.77	1.01	3.7	10.6	5.34	1.09	3.2	7.8

St = stature, *TL* = thigh length, *LLL* = lower leg length, *FL* = foot length, *FB* = foot breadth, *FH* = foot height, *LL* = leg length.

Table 3
The Pearson's correlation analysis between lower limb parameters and stature.

Parameters	*R*
LLL	0.776[a]
LL	0.730[a]
FL	0.690[a]
TL	0.675[a]
FB	0.517[a]
FH	0.322[a]

St = stature, *TL* = thigh length, *LLL* = lower leg length, *FL* = foot length, *FB* = foot breadth, *FH* = foot height, *LL* = leg length.
[a] $p < 0.01$.

3. Results

Table 1 showed descriptive statistics for lower limb parameters in males and females. The mean age for males in this study was 59 years ($n = 69$) and 64 years in females ($n = 31$), and generally, the females were nearly 5 years older than the males (Table 2). The lower limb dimensions showed normal data distribution by using the Kolmogorov–Smirnov test. The mean values of lower limb parameters and their standard deviations were significantly higher in males than in females ($p < 0.05$) (Table 2). However, the values may not be entirely representative in this study as males have a higher number of samples compared to females.

Table 4
Linear regression equations for stature (*cm*) estimation in males, females and combined sex.

Parameters	Equations	*R*	R^2	*SEE*
Male				
LLL	79.412 + 1.809 *LLL*	0.72	0.52[b]	5.03
LL	95.102 + 1.677 *LL*	0.63	0.40[b]	5.64
TL	106.039 + 1.324 *TL*	0.60	0.37[b]	5.79
FL	102.707 + 2.588 *FL*	0.60	0.36[b]	5.83
FH	151.692 + 2.280 *FH*	0.32	0.10[b]	6.89
FB	131.427 + 3.613 *FB*	0.29	0.08[b]	6.96
Female				
LL	98.158 + 1.426 *LL*	0.54	0.30[b]	5.45
LLL	96.922 + 1.282 *LLL*	0.53	0.28[b]	5.49
FL	111.417 + 1.875 *FL*	0.39	0.16[a]	5.97
TL	121.256 + 0.773 *TL*	0.33	0.11	6.13
FB	132.215 + 2.416 *FB*	0.23	0.05	6.32
FH	148.276 + 0.815 *FH*	0.14	0.02	6.43
Combined sex				
LLL	63.845 + 2.111 *LLL*	0.78	0.60[b]	5.68
LL	74.255 + 2.141 *LL*	0.73	0.53[b]	6.16
FL	81.912 + 3.385 *FL*	0.69	0.48[b]	6.52
TL	88.074 + 1.688 *TL*	0.67	0.46[b]	6.64
FH	145.6 + 2.74 *FH*	0.32	0.10[b]	8.53
FB	100.56 + 6.72 *FB*	0.52	0.27[b]	7.71

St = stature, *TL* = thigh length, *LLL* = lower leg length, *FL* = foot length, *FB* = foot breadth, *FH* = foot height, *LL* = leg length.
[a] $p < 0.05$.
[b] $p < 0.01$.

Table 5
Multiple regressions for stature estimation in males, females and combined sex.

Model	Equations	R	R^2	SEE
Male				
1	$Y = 45.06 + 0.56\ TL + 0.95\ LLL + 0.309\ LL + 0.318\ FL) + 2.74\ (FB) + 0.79\ (FH)$	0.80	0.64[a]	4.52
2	$Y = 44.64 + 0.60\ (TL) + 0.98\ (LLL) + 0.35\ (LL) + +2.99\ (FB)\ 0.86(FH)$	0.79	0.63[a]	4.50
3	$Y = 45.39 + 0.61\ (TL) + 1.29\ (LLL) + 3.03\ (FB) + 0.53(FH)$	0.79	0.63[a]	4.49
4	$Y = 46.30 + 0.62\ (TL) + 1.37\ (LLL) + 2.85\ (FB)$	0.79	0.63[a]	4.48
Female				
1	$Y = 72.26 + 0.15\ (TL) - 6.04\ (LLL) + 7.41\ (LL) + 1.45\ (FL) - 1.32\ (FB) + 6.17\ (FH)$	0.67	0.45[a]	5.27
2	$Y = 76 - 6.43\ (LLL) + 7.86\ (LL) + 1.49\ (FL) - 1.42\ (FB) + 6.56\ (FH)$	0.67	0.45[a]	5.18
3	$Y = 72.28 - 5.39\ (LLL) + 6.79\ (LL) + 1.15\ (FL) + 5.61\ (FH)$	0.66	0.43[a]	5.13
4	$Y = 87 - 5.12\ (LLL) + 6.71\ (LL) + 5.97\ (FH)$	0.62	0.39[a]	5.23
Combined sex				
1	$Y = 38.05 + 0.61\ (TL) + 0.87\ (LLL) + 0.44\ (LL) + 0.52\ (FL) + 2.65\ (FB) + 0.51\ (FH)$	0.85	0.72[a]	4.90
2	$Y = 38.272 + 0\ 0.61\ (TL) + 1.11\ (LLL) + 0.21\ (LL) + 0.57\ (FL) + 2.60\ (FB)$	0.85	0.72[a]	4.89
3	$Y = 38.310 + 0.62\ (TL) + 1.28\ (LLL) + 0.57\ (FL) + 2.69\ (FB)$	0.85	0.72[a]	4.87
4	$Y = 38.426 + 0.68\ (TL) + 1.41\ (LLL) + 3.14\ (FB)$	0.84	0.71[a]	4.89

St = stature, *TL* = thigh length, *LLL* = lower leg length, *FL* = foot length, *FB* = foot breadth, *FH* = foot height, *LL* = leg length.
[a] $p < 0.01$.

The Pearson's correlation showed good correlations between lower limb parameters and stature, in which *LLL* exhibited the highest correlation ($R = 0.776$) followed by *LL*, *FL*, *TL*, *FB* and *FH* ($R = 0.322$) (Table 3). A summary of linear regressions in males, females and combined sex was tabulated in Table 4. By using the linear regression, the stature can be estimated from mutilated or fragmentary body parts by using the regression: $\boldsymbol{y}$ (stature) = $\boldsymbol{b}$ (constant) + $\boldsymbol{a}$ (regression coefficient of the independent parameter) χ.

The regression in combined sex showed that *LLL* has a coefficient variance (R^2) of 60%. This means that 60% of variation was contributed by the parameters, while the remaining 40% of variation was due to random error (Table 4). The variance was subsequently reduced for each parameter that is, *LL* (53%), *FL* (48%), and *TL* (46%), respectively. The regression based on *LLL* in combined sex showed the lowest standard error of estimation (*SEE*) i.e. 5.68 compared to all other parameters (Table 4).

The multiple regression analysis had produced regressions by using various combinations of all six parameters. In combined sex, the multiple regressions showed lower *SEE* (4.87–4.90) (Table 5) than that in linear regressions (5.68–8.53) (Table 4). In males, the regressions based on *TL*, *LLL* and *FB* showed the lowest *SEE* (4.48) ($p < 0.01$) (Table 5), while in females, the regression based on *LLL*, *LL*, *FL* and *FH* showed the least *SEE* (5.13) ($p < 0.01$) (Table 5). The *SEE* was comparatively slightly higher in females (5.13) than in males (4.48), which could be explained by a higher number of males in this study ($n = 69$) than females ($n = 31$). Further explanation was provided for by greater variance in females (43%) than in males (63%), in which 43% of variation was contributed by the parameters in females compared to 63% of variation contributed by the parameters in males.

The regressions were subsequently cross-validated against the study sample. The results showed that there was no significant difference between known stature and estimated stature by using paired *T*-test ($p > 0.05$). The mean difference between known stature and estimated stature was 0.86 cm in males, which ranged from 1.1 *cm* to 2.4 *cm*. The mean difference between known stature and estimated stature was 1.96 *cm* in females, which ranged from 4.4 *cm* to 5.1 *cm* (Table 6). By using the independent sample *T*-test, it was found that there was no significant difference in stature estimation in both males and females ($p > 0.05$) (Table 7).

From 10 study samples, each sample was measured twice for leg length by each observer. By using paired sample *T*-test, there was no significant difference between the two measurements taken by each observer ($p > 0.05$) (Table 8). There was also no significant difference between the measurements taken by two independent observers by using independent sample *T*-test ($p > 0.05$) (Table 9). In this study, the technical error of measurement (*TEM*) and the relative *TEM* were determined to be 0. The *TEM* is a determination of an accuracy index, which measures the standard deviation between repeated measures by the observers.[17] The *TEM* (% *TEM*) provides an estimate of the error magnitude relative to the size of measurement, which is analogous to the coefficient of variation.[17] The coefficient of reliability ranged between 0 (not reliable) to 1 (complete reliability).[17] The coefficient of reliability (*R*) in this study was 1.[24] This confirmed the usefulness of the regressions produced for stature estimation in the Malaysian population.

Table 6
Descriptive statistics of mean values of known stature and estimated stature in males and females.

		N	Min	Max	Mean	SD	SEM
Known stature	Male	69	149.1	186.1	164.84	7.21	0.86
	Female	31	140.0	165.3	152.62	6.38	1.14
Estimated stature	Male	69	151.5	185.0	163.98	6.44	0.77
	Female	31	145.1	169.7	154.59	4.99	0.89

The table showed only slight difference between known and estimated stature in both males and females.

Table 7
Independent sample *T*-test between known and estimated stature in males and females.

	t	df	Sig. (2-tailed)
Known stature	8.10	98	0.87
Estimated stature	7.18	98	0.12

The table showed no significant difference between known and estimated stature in males and females ($p > 0.05$).

Table 8
Paired *T*-test for intra-observer error analysis.

		Mean	N	SD	SEM
Pair 1	Observer 1a	40.90	10	1.66	0.52
	Observer 1b	40.90	10	1.66	0.52
Pair 2	Observer 2a	40.90	10	1.66	0.52
	Observer 2b	40.90	10	1.66	0.52

Observer 1a and 1b represented the two measurements by observer 1, and observer 2a and 2b represented the two measurements by observer 2.

Table 9
Independent sample ***T***-test between observer 1 and observer 2.

	t	df	Sig. (2-tailed)
Known stature	0.00	18	1.00
Estimated stature	0.00	18	1.00

The table showed no significant difference between observer 1 and 2 in anthropometric measurements of leg length ($p > 0.05$).

Table 10
Comparison of correlation between stature and anthropometric measurements from Krishnan and Sharma (2007) and the present study.

Parameter	Krishnan and Sharma (2007)		The present study	
	Male	Female	Male	Female
	St	*St*	*St*	*St*
Pearson correlation (*R*)				
FB	0.324	0.323	0.287	0.230
FL	0.741	0.734	0.598	0.394

St = stature, *FB* = foot breadth, *FL* = foot length.

4. Discussion

Previous research studies have studied different parts of the body to establish a relationship between stature and body segments. Studies have shown that lower extremity have a greater association with body stature than that with upper extremity.[3] This study has performed measurements on lower limb parameters to relate with stature, in which several anatomical landmarks have been carefully chosen on intact body surfaces. The results showed that there were close approximation between estimated stature and known stature in the Malaysian population in males, females and combined sex.

The lower limb parameters exhibited significant correlations with stature, which was in accordance with Ozaslan et al.[3] From the parameters, foot breadth and foot height had shown significant correlations with stature, in accordance with that in the literature.[18–22] Comparatively, the *LLL* had provided the highest accuracy for stature estimation. The regressions were cross-validated on the study sample, which showed close approximation of stature between known and estimated values, which was in agreement with Krishnan and Sharma (2007).[13]

Table 10 showed the comparable correlation coefficients of foot length and foot breadth with stature in the present study and in Krishnan and Sharma (2007). Foot breadth values were comparable in males and females in both studies. However, foot length showed lower correlations in this study than in Krishnan and Sharma (2007) (Table 10). The discrepancies could be attributed to different equipments used in their measurements, in which measuring a measuring tape and sliding calipers have been used in this study and in Krishnan and Sharma (2007), respectively. Nevertheless, foot length in males showed a good correlation ($R = 0.598$) in this study, although slightly lower than in Krishnan and Sharma (2007) ($R = 0.741$) (Table 10).

Table 11 showed regression equations and *SEE* in this study and in Ozaslan et al. (2003) in males and females. Generally, the equations based on *TL*, *LLL* and *LL* showed comparable values of variance (R^2) and *SEE* in both studies (Table 11), although the regressions based on *LLL* and *LL* in females showed slightly higher *SEE* in this study that in Ozaslan et al. (2003) (Table 11). Table 12 showed regressions based on foot length and foot breadth in his study and in Krishnan and Sharma (2007) in males and females. Comparatively, the *SEE* from the regressions was only slightly higher in this study than those by Krishnan and Sharma (2007). In brief, the regressions achieved in this study had confirmed the usefulness of lower leg parameters for stature estimation in the Malaysian population. It will, therefore be of great help to the forensic and physical anthropologists to proceed with stature estimation based on lower limb parameters.

Table 12
Comparison of *SEE* with multiple regression equations for estimation of stature (*cm*) from Krishnan and Sharma (2007) and the present study.

Krishnan and Sharma (2007)		The present study	
Male	*SEE*	**Male**	*SEE*
$St = 99.59 + 1.51\ FL + 3.29\ FB$	3.02	$St = 93.05 + 2.44\ FL + 1.44\ FB$	5.82
Female		**Female**	
$St = 79.36 + 2.60\ FL + 2.11\ FB$	2.98	$St = 109.22 + 1.75\ FL + 0.59\ FB$	6.07

St = stature, *FB* = foot breadth, *FL* = foot length.

Admittedly, the literature had documented variations that exist between ethnic origins and racial affiliation in relation to body dimensions, and its relations to locomotor pattern, lifestyle and energy expenditure.[23,24] The Malaysian people, in generally is mostly short in stature, lead an active lifestyle and lives in a hot climate compared to the European and North American people, who are generally taller, led a slightly different lifestyle and lived in cold climate. Comparatively, the energy expenditure in cold climate is much less than that in a hot climate. The environmental factor may have some influence in people's life style, which consequently lead to differences in bone configuration and dimension in the population. This is the main reason that studies need to be done in a population to represent its people with specific equations for stature estimation.

There was a recent encounter by the author and the police at a crime scene, whereby a leg has been found in an abandoned apartment house. The remaining parts of the body were dismembered, and packed in separate plastic bags in different parts of the house. The identification of the deceased was based on stature estimation for identification, besides resorting to *DNA* analysis and physical characteristics. At the time, stature was estimated by resorting to the established regressions based on the European and North American populations,[25] as there were no regressions based on the Malaysian population. This is a hypothetical case of dismembered human remains for identification purposes, which justify a research on stature estimation for the Malaysian population.

5. Conclusion

It is concluded that this study has performed assessment of lower limb dimensions measured on body surfaces for estimation of stature. This has brought significant implications in the assessment of fragmentary body remains and forensic population

Table 11
Comparison of direct regression analysis including *R*, R^2 and *SEE* from Ozaslan et al. (2003) and the present study.

Regression analysis	Ozaslan et al. (2003)						The present study					
	Males			Females			Males			Females		
	R	R^2	*SEE*	*R*	R^2	*SEE*	*R*	R^2	*SEE*	*R*	R^2	*SEE*
TL	0.50	0.20	5.94	0.23	0.05	6.31	0.60	0.37	5.79	0.33	0.11	6.13
LLL	0.75	0.56	4.39	0.80	0.65	3.86	0.72	0.52	5.03	0.53	0.28	5.49
LL	0.74	0.55	4.46	0.79	0.63	3.93	0.63	0.40	5.64	0.54	0.30	5.45

TL = Thigh length, *LLL* = lower leg length, *LL* = leg length.

samples for identification purposes in the Malaysian population. It is worthwhile to mention that this study is a pioneer study in forensic anthropology amongst the Malaysian population, which may be useful for the police, forensic scientists and law enforcement agencies. In future, this study can be extended to other bones such as upper limbs and spinal vertebrae for compilation purposes and comparison with other research studies.

Ethical approval

Approved by institution (FF-218-2012).

Funding

Funded by Universiti Kebangsaan Malaysia Medical Centre.

Conflict of interest

All authors declared no conflict of interest.

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